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An Assessment of the Computer Science Activities of the Office of Naval Research

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Panel for the Assessment of Computer Science Activities of the
Office of Naval Research
Naval Studies Board
Commission on Physical Sciences, Mathematics, and Resources
National Research Council

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This report has been reviewed by a group other than the authors according to procedures approved by a Report Review Committee consisting of members of the National Academy of Sciences, the National Academy of Engineering, and the Institute of Medicine.

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Panel for the Assessment of Computer Science
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Various Naval research personnel reported on their programs and their dispositions of computer science research monies. In addition, Robert Grafton, Richard Lau, Alan Meyrowitz, and David Mizell from the Office of Naval Research, and Bruce Wald from the Naval Research Laboratory attended most of the open portion of the meeting.

*Drs. Corbato, Raibert, and Rivest were unable to attend the assessment meeting but participated in the review of the report.

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Naval Studies Board

Commission on Physical Sciences,
Mathematics, and Resources

CONTENTS

PREFACE

This is the report of the Panel on Assessment of Computer Science Research Activities of the Office of Naval Research (ONR). The Panel was formed under the auspices of the Naval Studies Board of the Commission on Physical Sciences, Mathematics, and Resources of the National Research Council (NRC).

The ONR is responsible for all the basic research conducted by the Navy. A portion of ONR's funds is earmarked for computer science (CS) research. A portion of the CS funds is administered by the Contract Research Program (CRP) of ONR. The Panel was requested to evaluate the research program of the CRP and also related basic research on computer science being performed elsewhere in the Navy (e.g., the Naval Research Laboratory, the Naval Air Systems Command, NAVSEA, and the Space and Naval Warfare Systems Command). Representatives of the CRP and the various Naval Commands who receive computer science research funds from ONR made presentations to the Panel. (The agenda is attached as Appendix A.) The Panel evaluated the information presented and offers its comments in this report. Some of the Panel's comments are directed to the ONR in general, including all claimants, while other comments are directed to CRP in particular.

The Panel was originally requested to present its evaluation in a letter report to ONR. In early 1986, however, the NRC requested that the Panel's brief report be presented in a normal report format while also undergoing the regular NRC review process. Because the funds provided under the original charge were not sufficient for a series of meetings, the Panel did not have the opportunity to review in depth all current ONR projects, to investigate extensively the Navy's needs in computing, to study at length the internal procedures of the CRP, or to widen the audience of the report. Consequently, the Panel's comments on these matters are limited to general observations directed to ONR program managers.

Most of the comments contained in this report are derived from the information presented to the Panel at its meeting in October 1985. Changes in the Navy's priorities or methods of doing business since that date may not be reflected here. The Panel had no access to classified information; in some areas, the Navy may actually be using computing technology of different technical sophistication than was shown.

The Panel was generally pleased with the way in which the Navy has conducted its computer science program and believes that the program has made many good investments and has an excellent record of successes. The Panel has a few minor concerns, which will be expressed in this report as suggestions for improvements.

On behalf of the Panel, I would like to thank the members of the ONR staff, as well as those from the various Naval Commands and Laboratories, who participated in this project, as well as the liaison representatives and NRC staff.

Peter J. Denning, Chairman
Panel for the Assessment of Computer Science Activities of the Office of Naval Research

ABSTRACT

A Panel of the Naval Studies Board of the National Research Council met for two days in October 1985 to assess the computer science programs of the Office of Naval Research (ONR). These programs are supported by the Contract Research Program (CRP) as well as the Naval Research Laboratory (NRL), the Naval Air Systems Command, and the Space and Naval Warfare Systems Command. Based principally on information presented to the Panel at the two-day meeting, as well as their knowledge of the field, the panel offers comments on the computer science research of the Navy and suggestions for further improvement of a program that has already made numerous good investments with a number of the best projects in the country and an excellent record of success. ONR, for example, was encouraged to take further advantage of its entrepreneurial flexibility to improve technology transfer between computer science and the Navy by mechanisms such as focused meetings, consulting, and scientific exchange programs. Four additional mechanisms for obtaining advice on the computer science program and project evaluation were suggested: contractor's workshops, advisory panels for program review and general guidance, more use of standard ONR formats for project descriptions, and better publicity for ONR projects. The Panel also identified five potential new areas requiring substantial basic research: real-time systems, system structure concepts, parallel programming, formalization of expert systems, and representation of physical objects.

1. SUMMARY

At the request of the Office of Naval Research (ONR), a Panel of the Naval Studies Board (acting on behalf of the then currently inactive Computer Science and Technology Board) of the National Research Council was convened to assess the computer science programs of ONR. This program embraces research funded by the Contract Research Program (CRP) and related basic research being funded elsewhere in the Navy (for example, the Naval Research Laboratory, the Naval Air Systems Command, and the Space and Naval Warfare Systems Command). The Panel held a two-day meeting at the National Academy of Sciences in October 1985, at which various naval research personnel reported on their programs and their dispositions of computer science research monies. (The agenda for this meeting is attached as Appendix A.) Based principally on the information presented to the Panel at that meeting, the Panel concluded that CRP program managers have made numerous good choices: they have sponsored some of the best projects in the country and have had an excellent record of successes.

In this report, the Panel comments on the ONR's computer science research program and offers a few suggestions for improvement. The CRP and the other claimants on ONR funds were encouraged to take further advantage of their entrepreneurial flexibility to improve technology transfer between computer science and the Navy by mechanisms such as focused meetings, consulting, and scientific exchange programs. While not able to offer a technical review of each of the currently funded projects of the CRP or the other claimant commands, the Panel noted a number of these projects whose significance has already been recognized among computer scientists.

Additional mechanisms for obtaining advice on the computer science program and the evaluation of projects were suggested, notably, semiannual contractor's workshops, a formal advisory panel for program review and general guidance, and more publicity of research results. The Panel also recommended more prominent use of the ONR standard format for describing projects.

Finally, the Panel identified five potential new areas of investigation requiring substantial basic research, viz., real-time systems, system structure concepts, parallel programming, formalization of expert systems, and representation of physical objects, and offered brief comments on each.

2. BACKGROUND ON COMPUTER SCIENCE

2.1. The Discipline

The Panel understands that ONR senior management sees computer science as a young discipline that is not yet fully established as are the other, more traditional disciplines. To command the support from ONR that it requires and deserves, computer science must be shown to have firm scientific roots, and it must also be shown to be important to the Navy. The following subsections are brief summaries of the evidence for these two claims.

Computer science is the systematic study of processes that transform information: principles underlying their analysis, implementation, efficiency, design, and application. The fundamental question underlying all of computer science is "What can be automated?"[1] This discipline was born in the mid-1940s with the invention of the stored-program electronic computer and has grown rapidly ever since. The roots of computer science can be traced back several centuries in mathematics, engineering, and logic.

Computer science can be viewed as a discipline of eleven subfields. Each subfield addresses fundamental questions and has made significant intellectual and practical accomplishments. The subfields of computer science are[2]

- Programming languages and methodology
- Algorithms and data structures
- Architecture (hardware)
- Theory
- Numerical computation
- Database and information retrieval systems
- Human interface
- Parallel and distributed computation
- Operating systems
- Dependable computing
- Artificial intelligence

The subfields are by no means mutually exclusive. Each has its own theoretical component; most have devised specialized programming languages as notation for algorithms and data structures; most implementations are on machines with operating systems connected to networks; most deal with problems having components that can execute in parallel.

Methodologies for design and analysis pervade all subfields. In computer science, these methodologies are not treated as separate subject areas. For example, software engineering is a design methodology that embraces all eleven areas.

2.2. The Navy's Interest

Computer science is a critical discipline to the Navy. The E-2C Airborne Early Warning aircraft, the Aegis Anti-Air Warfare systems, and signal-processing methods used in passive sonar arrays illustrate the importance of computing in today's air, surface, and submarine naval operations.

Computing will play an even more important role in future military systems. Computerizing algorithmic tasks that are currently performed by humans can increase system performance, overcome personnel shortages, and compensate for the lower IQ levels of an all-volunteer Navy. Computerization can reduce manpower requirements as well as improve the safety, logistics, financial, and weight problems that accompany large crews. The U.S. Navy expects to use the nation's computing expertise--which far surpasses that of other nations--as a "force multiplier" that counters numerical disadvantage with superior technology.

Some of the Navy's specific needs in improved computing include real-time systems, command and control systems, fault-tolerant distributed computing, innovative concepts for system structuring, extensions of software engineering to parallel and distributed systems, reliable and predictable expert systems, automated real-time logistics planning systems, and automated mechanisms for manufacturing replacement parts for naval equipment. In a later section of this report, the Panel recommends greater emphasis on some of these areas.

It may be tempting to conclude that engineering, not research, is the best path to meeting the Navy's pressing needs in automation--i.e., that a greater percentage of funds needs to be allocated for applied research and development (categories 6.2 and higher) than for basic research (category 6.1). The Panel believes that this conclusion would be wrong and detrimental to the Navy's interest. For example, engineering technology is producing new types of sensors, front-end processors, control mechanisms, and networks at a much higher pace than the research community is discovering principles for integrating these components into reliable, fault-tolerant, real-time systems. Software engineering is not producing concepts for programming parallel and distributed systems at the same pace that processors are being lashed together into arrays or computers into distributed systems. Theories of knowledge representation are insufficiently advanced to make expert systems reliable or their performance in untested situations predictable. The architecture concepts needed for real-time systems, programming concepts for parallel and distributed systems, dependability concepts for large distributed systems, and knowledge representation concepts needed for expert systems are not being studied by the engineers who build these systems. They are being studied by scientists, but to a much lesser extent than is needed to discover solutions to the problem. The Navy needs to give more emphasis to basic research in these areas.

There is quantitative support for the claim that basic research has as much to contribute to the advancement of computing as has engineering. In 1984, Bentley reported a study by Rice about the improvements in the performance of numerical codes since 1945.[3] Over that period, engineering advances, as measured by speeds of the fastest computers, were responsible for a factor of 10^6 speedup. Over the same period, scientific advances, as measured by the reduction in operation counts of algorithms, were responsible for another factor of 10^6 speedup. The overall performance improvement, a factor of 10^{12}, is attributable equally to scientific and engineering advances.

3. TECHNOLOGY TRANSFER

Based on comments made by various persons making presentations, the Panel perceives that technology transfer is important to the Navy. By this is meant the bidirectional flow of information, results, and know-how between the fleet and the computer science community. Close interaction between Navy personnel and computer science researchers will help to speed the introduction of leading-edge computing technology into naval systems and operations. Some of the large, distributed-systems problems facing the Navy can be an important stimulus to a large segment of computer science researchers.

The information presented to the Panel showed a wide variation in the sophistication of computer technology currently deployed in the fleet. In some domains, such as signal processing, deployed systems are advanced far beyond their commercial counterparts. Other domains appear to lag the civilian state of the art; for example, the Panel was told of a front-line avionics system (not the A-7 System) that was built using hardware and software methods that are two decades old. Systems lagging civilian technology are, in the Panel's opinion, needlessly expensive and offer reduced performance. (It is possible that the Navy has more advanced, but classified, computing technologies in these domains.)

The software research at Naval Research Laboratories, led by Parnas, and motivated by the A-7 Corsair light attack aircraft, is an example of technology transfer at its best. The project has led to important new techniques in software engineering and made substantial contributions to both theory and practice. Some of the results are in current use in the A-7 Avionics System in the Navy's China Lake group, for maintaining the aircraft's avionics software. The technology transfer was bidirectional: the real problems inherent in the system led Parnas to fundamental insights that have been disseminated to a wide community of software engineers. This project involves all four interested groups: academic researchers, naval research laboratories, development contractors, and the fleet.

The Panel appreciates that the CRP and other claimants may be impeded from reaching their goals in technology transfer by factors beyond the scope of this report, for example, procurement policies and cost structures of defense contracts. Nonetheless, the Panel would like to encourage especially CRP but also the other claimants to take additional advantage of their entrepreneurial flexibility to improve technology transfer between computer science and the Navy. Some of the more promising mechanisms follow.

Meetings--focus on a specific technology area; seek attendance by a mixture of people from among universities, research contractors, naval laboratories, development contractors, and operational naval personnel; keep each meeting small to encourage interactions; arrange for the proceedings of these meetings to be published and distributed.

Consulting--seek personal interactions between qualified computer scientists and Naval Commands.

Exchange Programs--invite academics to visit naval laboratories or contractor facilities while on sabbatical; permit naval scientists to spend a year on campus.

4. NAVY FUNDING OF COMPUTER SCIENCE RESEARCH

4.1. General Picture

Table 4.1 summarizes basic research funds (category 6.1) for computer science in the major agencies. The Navy contributes about 4 percent of the overall support for computer science research.

The ONR is responsible for all the basic research conducted by the Navy. A major goal of the ONR Contract Research Program (CRP) in computer science is to fund work that does not overlap with DARPA's program and bears as directly as possible on needs unique to the Navy. It is clear that ONR must try to accomplish its goals with significantly less money than the Information Science Technology office at DARPA. Consequently, ONR must choose its problems and contractors with great care.

A portion of ONR's funds is earmarked for computer science (CS) research. A portion of the CS funds is administered by the CRP of ONR, through the Computer Science Division (CSD) of the Engineering Sciences Directorate, while another portion is allocated directly by ONR to other Navy claimants, such as the Naval Research Laboratory and the Naval Commands. Although the ONR-CRP funds a relatively small portion of all computer science research, CRP has generally chosen excellent projects, and the return on investment has been high, based on such indices as the skills and prestige of the principal investigators, number of publications, understood significance of the findings, and impact on operational naval systems.

The Navy expects the CRP to be entrepreneurial, i.e., to take informed risks for high potential payoff. Through CRP, the Navy hopes to identify the small investments in computer technology that are expected to have the greatest impact. The intent is to discover the best technology and begin moving Navy personnel in new directions. In pursuit of this goal, CRP places considerable responsibility on the program managers. The Panel believes that this is the primary reason for CRP's success.

TABLE 1 Estimated Basic Computer Science Research Funding by Federal Agencies for Fiscal Year 1986

Defense Advanced Research Projects Agency (DARPA)	>$190 million
National Science Foundation (NSF)	$ 40 million
Navy	$ 10 million
Department of Energy	$ 10 million
Army	$ 5 million
Air Force Office of Scientific Research	$ 4 million

4.2. ONR-CRP's Approach to Funding Research

In October 1985, the ONR computer science research plan was based on a model that may be summarized as follows:

1. Slightly under half of ONR's computer science research funds are allocated to the research activities of the Naval laboratories and other non-CRP claimants. Decisions about appropriate research directions are made by the laboratory managers in consultation with the laboratory scientists, where the work is performed in house, and by program managers, where the work is performed external to the Navy.

2. Slightly over half of ONR's computer science research funds are allocated to small ($50,000 per year) and medium-sized ($150,000 per year) outside contracts administered through CRP. Decisions among alternative contractors are made by the relevant CRP program managers, who rely in turn on informal advice from leading computer scientists. The technical skills and prestige of the principal investigator carry considerable weight in the decision on whether to fund a proposal. Program managers are encouraged to have an entrepreneurial style; they have the authority to choose high-risk projects whose payoff would be very high. Program managers are responsible for tracking the progress of each of their projects and have the authority to withdraw support from projects that are faltering over a period of a year or two.

3. New research directions can be implemented in the form of accelerated research initiatives (ARIs) or core programs. ARIs are basic research programs in which funding is concentrated for a limited period (nominally 5 years) in order to accelerate progress in the field of research.

It is useful to compare the above ONR model with those used by the two largest funding agencies for computer science research, NSF and DARPA (see Table 1). The NSF places considerable weight on peer review of proposals; once a proposal is accepted, it is funded in the form of a grant. Follow-up evaluation is used for large projects, such as the Experimental CS Program. The NSF tries to cover a broad range of subdisciplines and does so with many awards.

In contrast, DARPA places considerable weight on the judgment of its program managers, with advice from leading researchers; once a proposal is accepted, it is funded in the form of a contract. DARPA also places considerable weight on close monitoring of the progress and results from its projects; its primary tool is regular contractor meetings at which the set of contractors constitutes a review panel for the individuals who make progress reports. DARPA focuses on a few selected areas and makes awards in large sums to a relatively small group of contractors.

The ONR CRP follows a model closer to that of DARPA. The Panel was generally pleased with this approach. It appeared that CRP holds contractor meetings less frequently than DARPA does.

4.3. Current CRP Projects

The current projects receiving ONR-CRP funding are grouped into categories and listed in Table 2. The Panel listened to short descriptions by each program manager of each task in his area. The Panel did not, however, attempt a technical review of the individual tasks and for that reason will not offer an evaluation of tasks here. The Panel does believe that this set of projects includes a number whose significance has already been recognized among computer scientists: systolic processing research at Carnegie-Mellon University (work of Kung); higher-order languages and architectures research at SRI International (work of Goguen); semantic theory research at Oxford University (work of Hoare); visual programming research at Brown University (work of van Dam); Poker programming environment research at the University of Washington (work of Snyder); program visualization research at SRI International (work of Moriconi); theorem prover research at the University of Texas (work of Boyer and Moore); analogy system research at Carnegie-Mellon University (work of Carbonnel); and inferential programming research at Carnegie-Mellon University (work of Scott).

TABLE 2 ONR Contract Research Program Project Areas in Fiscal Year 1986

Area	Funds Fiscal Year 1986	No. of Tasks
Artificial Intelligence	$1.7 million	17
Knowledge acquisition		
Knowledge representation		
Automated reasoning		
Robotics	$1.2 million	7
Reasoning		
Sensing		
Manipulation		
Mobility		
Software Engineering	$1.5 million	17
Software foundations		
Science of software		
Computer Architecture	$1.0 million	15
Parallelism		
Distributed systems		

In listening to the presentations of projects, the Panel noted variations in presentation style. The program manager for software engineering used a style that was especially helpful: with each project he stated an hypothesis, and objective, and an approach. The hypotheses were sufficiently specific that reviewers would be able to assess the success of the project at meeting its goals. Each project had measurable milestones stated for it. The Panel understands that this information is derived from standard forms used by ONR to summarize all its projects. The Panel encouraged all the program managers of CRP to use this style when making presentations to outside review bodies.

During the presentations of the computer science programs, several items caught the Panel's attention. The Panel notes them here and encourages the program managers to clarify them in case they come up again in the future:

1. In the artificial intelligence area, it appears that projects to analyze and refine basic techniques are being judged with metrics that are more suited to exploratory projects. Some of the claims are stated nonquantitatively, making it difficult to assess progress. Examples are "changing to a better programming paradigm" and "improving the reliability of programs." The Panel understands that AI researchers have addressed some of the most difficult projects in computer science and that the nature of these problems frequently makes quantitative analysis difficult, but the Panel nonetheless encourages program managers to seek verifiable claims as they do in robotics, software engineering, and architecture. Examples of questions that researchers should be encouraged to explore are: How powerful is the method? What size problems can it handle? What are the ultimate limitations of the approach? What resources might be required for realistic tasks? The objective is to inject more quantification and evaluation into research to guide the discovery process and to enhance the ability to refine and improve the field.

2. Several of the theoretical computer science projects supported by the CRP listed vague, unspecific, or generic goals, such as "new approaches to algorithms," that obscured the relevance to the Navy's long-term objectives. The Panel encourages program managers to seek clearer statements of the goals of the theory projects and the potential benefits to the Navy.

3. There are several investigators who have been under contract to the Navy for lengthy periods, e.g., more than 7 years. It appears to the Panel that the benefits of their work were not clearly articulated. The Panel encourages the program managers to review such projects and state their benefits to the Navy more clearly.

4. There appears to be significant overlap between software engineering research in cooperating sequential processes (CSP) and artificial intelligence work in distributed computing. While the Panel has no objection to redundancy in research programs, it appears that the program managers were not encouraging the researchers to exchange ideas.

The Panel believes that program managers should make more systematic use of techniques to obtain advice and evaluation of projects. The Panel suggests four mechanisms that can be employed without compromising the successful style of CRP:

1. Follow DARPA's lead in holding contractor's workshops (at least one annually). Request each contractor to present a progress report and use an open discussion to ferret out weaknesses and identify strengths. With this technique, the contractors themselves review each other's projects; the workshops give important feedback to the program managers for evaluating progress. For added benefit, such workshops might also include noncontractors active in the field.
2. Follow NSF's lead by establishing a formal advisory panel that meets with program managers once or twice a year for program review and general guidance.
3. Make the ONR standard formats for describing projects more prominent. These formats request the investigator to state a vision of the expected long-term accomplishments of the project. They also request the investigator to state specific milestones that can be expected along the way. The Panel strongly encourages program managers to seek quantitative milestone statements, which observers can evaluate later to see whether they were achieved. (Examples of quantitative statements are: "Exhibit a prototype theorem prover with the following properties..." and "Develop lower bounds on the time to solve problems of X type on a mesh computer.")
4. Publicize important results, e.g., in an ONR newsletter or by a new publication similar to the National Research Council's News Report.

The first mechanism in the list above would help program managers to obtain regular and systematic information to assess which projects are doing well or poorly. The second mechanism would help program managers to evaluate their own performance in selecting projects and would give regular guidance about long-term research directions. The third mechanism would help observers assess the purposes and accomplishments of each project and each program area. The fourth would bring ONR accomplishments into wider prominence.

Some of the program managers discussed their feelings about project size. Some felt that theory projects could be adequately supported with as little as $50,000 per year but that a significant system-development project might require approximately $300,000 per year. The Panel believes that the figure for a system-development project may be low, given the costs of equipment and support personnel. The Panel would recommend a smaller number of well-done projects over a larger number of underfunded projects.

4.4 Summary of Findings and Recommendations

The Panel was generally pleased with what was presented and with Navy personnel. The Panel believes that, on the whole, the various computer science program managers have done a first-rate job in identifying and supporting good projects. From its broad science experience, the Panel judged that the CRP's computer science research program includes some of the best computer science projects in the country; the Panel cited ten examples. The Navy, and especially ONR's CRP, appears to have achieved an excellent return on investment for the research dollar. The strengths of the CRP program, especially, are its flexibility, its entrepreneurial style, and its success as a computer technology showcase for the rest of the Navy.

The CRP's basic approach to managing its program is successful and should be preserved. The main features are considerable responsibility given to program managers, encouragement of informed risk-taking, sticking with researchers of exceptional talent or expertise, and allocating a portion of the funds for accelerated research initiatives.

CRP and other claimants on ONR funds, such as NRL and the Systems Commands, are encouraged to review their mechanisms for obtaining advice and evaluating programs, looking especially at contractor meetings, an advisory panel, standard reporting formats, and improved publicity for results.

One of the strengths of the program is also a potential weakness: the success of the program depends strongly on the judgments of a few people. The Panel has suggested mechanisms that would get more advice for program managers without restricting their judgments or interfering with the other strengths of the program. The Panel emphasizes that there is no serious problem now.

Some areas of the technical program should be reviewed, including (1) nonquantitative claims made by some artificial-intelligence contractors, (2) relevance of theory areas to the long-term goals of the Navy, (3) flow of benefits from investigators who have received contracts for extended periods (over 7 years), and (4) overlaps between distributed computation in computer architecture and artificial intelligence. The Panel considers none of these matters serious.

5. POTENTIAL NEW RESEARCH DIRECTIONS

The Panel identified five areas of research that are critical to future naval systems but were not well covered by the computer science research efforts presented to the Panel in October 1985. All these areas require substantial basic research before practical results can be expected.

1. Real-Time Systems. The area of real-time systems is an engineering discipline looking for a scientific basis. The technology base for real-time systems is changing drastically. Because they are intrinsically highly parallel in structure, real-time systems are rapidly impacted by parallel architectures. Microelectronics is creating a new generation of sensors capabilities for dedicated, front-end processing of sensor data. Artificial intelligence offers the potential for increasing the capabilities of control systems. Distributed systems and high-speed networks are offering new ways to connect sensors, activators, processors, and other system components. A new ONR research initiative could seek to establish a scientific basis for a new generation of real-time systems that exploit these new potentials. Each of these technology areas has its own claims for attention and funding; the critical point is the need to integrate these technologies into coherent real-time systems.

2. System Structure Concepts. Most Naval computer systems include large, complex software systems that are the results of thousands of hours of human effort. Software engineering seems to be falling behind the effects of new technology, such as parallel and distributed computing systems. For example, environments for developing and debugging parallel and distributed programs have yet to be developed; multimedia mail and real-time conferencing have not been integrated into the programming environment; interface systems cannot interact with users at the level of abstraction of the application; distributed groups of people cannot collaborate effectively over the networks; software cannot easily be reused. There is a need to establish and evaluate new system development and structure concepts that deal with these new realities. A major need appears to be better integration of elements of the development process from application through hardware.

3. Parallel Computing. This area is important to Areas 1 and 2, above. It may be subdivided into two parts. First, future computer hardware will rely significantly on parallel processing to achieve greater computational power. However, little is known about parallel programming languages or how to write parallel software, so research should be directed to the effective use of current and future parallel machines. This research should encourage strong interaction between potential users and architects of parallel machines. The second subarea, distributed problem solving, involves concepts for coordinating multiple processors of different types, especially when the processors and communications are likely to fail. This is

obviously important in battlefield situations that may include substantial numbers of distinct computer systems.

4. Formalization of Expert Systems. The Panel heard statements that considerable reliance may be placed on expert systems in future Naval systems. Most expert systems today are based on informal heuristics and have uncertain limits of competence. The Panel believes that expert systems can be pushed much harder in the direction of greater reliability and competence. If the problem-solving model underlying the heuristic knowledge in an expert system could be represented formally, it would be possible to predict the behavior of the system in untested cases and, more generally, to understand the limits and capabilities of a given expert system. This would be especially important where expert systems are relied on to assist in time-critical decision-making.

5. Representation of Physical Objects. Naval systems rely on large numbers of complex physical objects and parts. One special type of reliance is on the replaceability of spare parts. Replaceability of parts, as well as their initial manufacture, would be significantly improved by representing the parts in computer-usable form from their inception. This would include not only the parts, their attributes, and their interconnections but also the decisions that went into their initial designs. Spare parts could be manufactured easily as needed by retrieving their descriptions from a database and feeding them to a programmable production facility.

References

1. B. Arden, editor. What Can be Automated? MIT Press, Cambridge, Mass., 1980.

2. For more information, see P. Denning, "What is Computer Science?" The Science of Computing column, American Scientist 73(1):16-19 (Jan.-Feb. 1985).

3. J. Bentley, "Perspective on Performance," Programming Pearls, Communications of ACM 27, 11:1087-1092 (Nov. 1984).

APPENDIX A

Panel on Assessment of Computer Science Activities of the
Office of Naval Research (ONR)
Naval Studies Board
Commission on Physical Sciences, Mathematics, and Resources (CPSMR)
National Research Council

Tuesday and Wednesday
8-9 October 1985
Room 453, Joseph Henry Building
2122 Pennsylvania Avenue, N.W.
Washington, D.C. 20418

Agenda

Tuesday, 8 October 1985

0900	Welcome and Introductions	Peter J. Denning, Chairman
0915	Introductory Statement and Discussion of "Potential Sources of Bias" and Conflicts of Interest	Lawrence E. McCray, Associate Executive Director, CPSMR
0930	Discussion Concerning the Nature of the Assessment	Ronald N. Kostoff, Director, Technical Assessment, ONR
0945	Issues to be Addressed	Arthur M. Diness Associate Director/ Research (Engineering Science), ONR
1015	BREAK	
1030	The Navy's Computer Science Program; User Requirements: --A Naval Research Laboratory Perspective	Bruce Wald, NRL
1100	--A Naval Air Systems Command Perspective	S. A. Gerhard Heicke, Nav Air
1130	Overview of ONR's Computer Science Program/Artificial Intelligence	Alan L. Meyrowitz, Information Sciences Division, ONR
1215	Discussion	
1230	LUNCH: Committee Dining Room 1	

1345	ONR Programs (Continued): --Robotics	Alan L. Meyrowitz
1415	--Software Engineering	Robert B. Grafton, Information Sciences Division, ONR
1515	BREAK	
1530	--Computer Architecture	David W. Mizell, Information Sciences Division, ONR
1630	Discussion	
1700	Recess until 0830	

Wednesday, 9 October 1985

0830	Other Navy Computer Science Research Programs: --Naval Research Laboratory	Randall Schumaker, Director, Navy Center for Applied Research in Artificial Intelligence, NRL
0930	--Naval Systems Commands: Naval Air Systems Command 6.1 Research	James G. Smith, Nav Air
1000	BREAK	
1015	--Space and Naval Warfare Systems Command	Steve Sachs, John Machado, and John Pucci, SpaWarS
1115	Other 6.1 Computer Science Research Programs of the Navy	
1200	General Discussion	
1230	LUNCH: Committee Dining Room 1	
1345	Panel Executive Session --Final Report Outline & Draft	Peter Denning
1630	Adjourn	